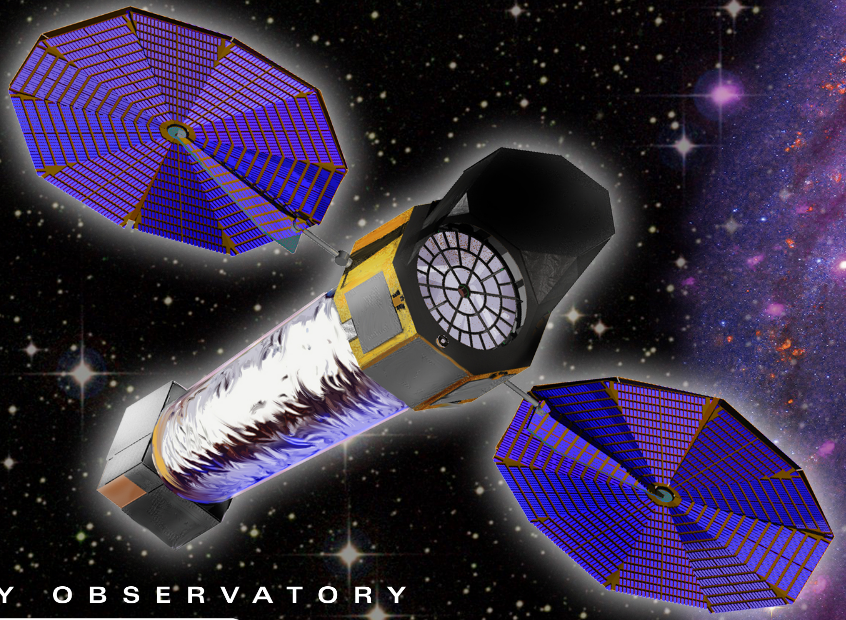
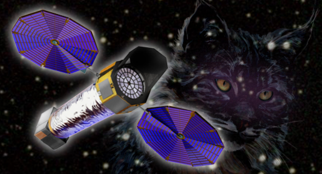
The *Lynx* Mission Concept
Revealing the Invisible Universe

Douglas A. Swartz (Deputy Study Scientist, MSFC)

-Presented On behalf of the *Lynx* Team



X-RAY OBSERVATORY
LYNX



Meet *Lynx*!

X-RAY OBSERVATORY LYNX

One of 4 large missions under study for the 2020 Astrophysics Decadal, Lynx is an X-ray observatory that will directly observe the dawn of supermassive black holes, reveal the invisible drivers of galaxy and structure formation, and trace the energetic side of stellar evolution and stellar ecosystems.

Lynx will contribute to nearly every area of astrophysics and provide synergistic observations with future-generation ground-based and space-based observatories, including gravitational wave detectors.

Lynx will provide unprecedented X-ray vision into the “Invisible” Universe with leaps in capability over *Chandra* and *ATHENA*:

- 50–100× gain in sensitivity via high throughput with high angular resolution
- 16× field of view for arcsecond or better imaging
- 10–20× higher spectral resolution for point-like and extended sources

THE SCIENCE

Lynx is designed to pursue three science pillars.

There are ample resources for many other programs, including those unexpected today.

It will be a discovery platform for all.

WWW.HIDDENCOSMOS.ORG

Lynx Study Office & STDT Activities

- Lynx Mirror Architecture Trade (LMAT) 01/2018 – 07/2018
  - recommend baseline optics design
  - adopted by STDT – 08/2018
- Large Mission Concept Studies Report Team (LRT) 05/2018 – 06/2018
- Lynx “science” website launched ~07/2018
  - https://www.hiddencosmos.org
- Interim Report submitted 08/2018
  - https://wwwastro.msfc.nasa.gov/lynx/docs/LynxInterimReport.pdf
- X-ray Grating Spectrometer architecture trade – 08/2018
- Mission Design Lab (at GSFC) – 09/2018
  - system-level independent assessment
- Second Architecture Design Study – 08/2018 – ongoing
  - requested by NASA to provide a less costly option and a range of scientific scope – 06/2018
- Special Section Journal of Astronomical Telescopes, Instruments, and Systems (JATIS) 10/2018 – 03/2019
- Large Mission Concept Independent Assessment Team (LCIT) – ongoing
  - a cost & technical credibility analysis & validation of the technical, cost, and schedule requirements defined by the Lynx study
- Science White Papers submitted to Decadal Survey – 03/2019

Decadal Deliverables Schedule

X-RAY OBSERVATORY LYNX

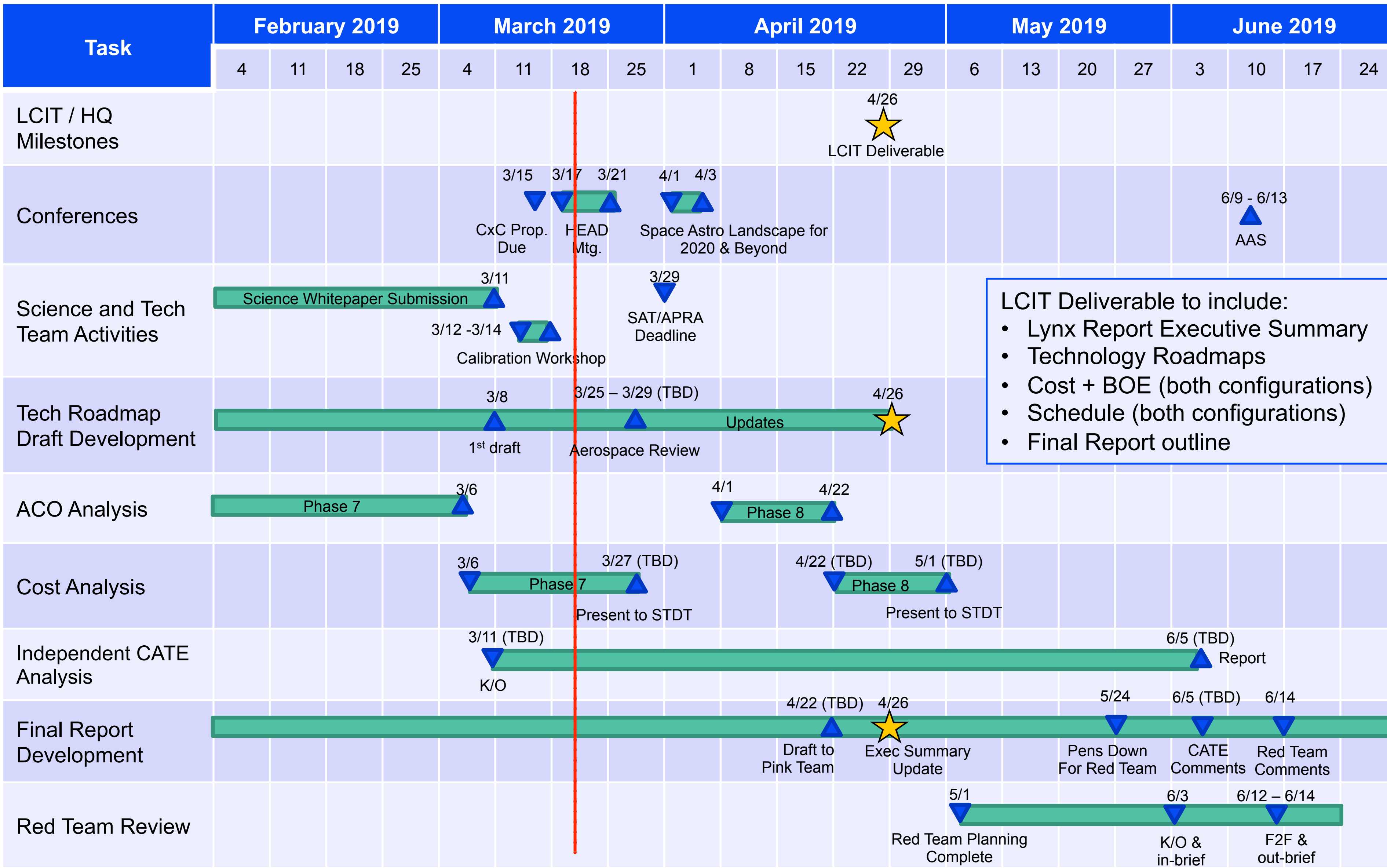
ASTROPHYSICS

NASA

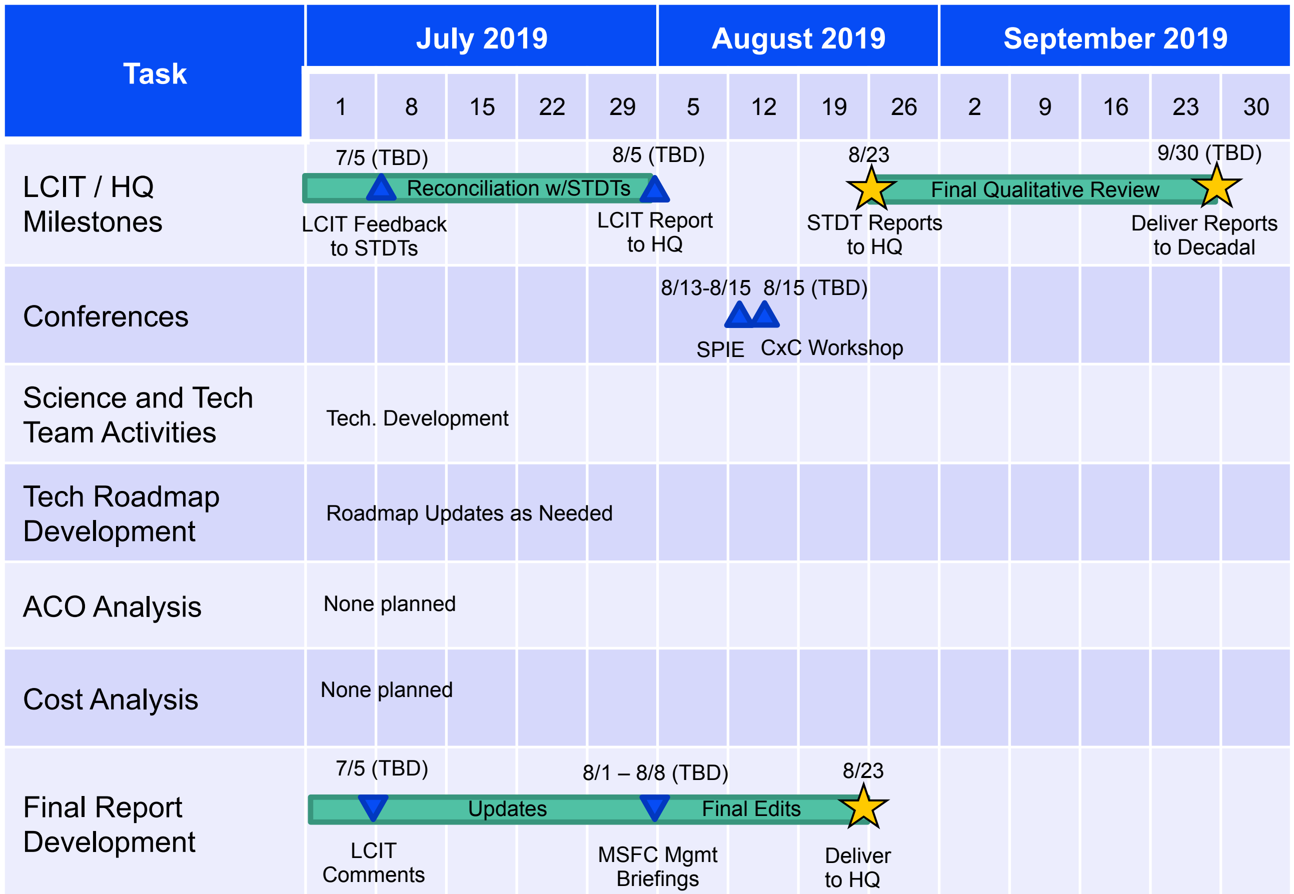
Study Deliverables

M1	**Comments on Study Requirements and Deliverables** – Accept the study requirements/deliverables and submit plan--- or – Provide rationale for modifying requirements/deliverables	**April 29, 2016**
O1	***Optional: Initial Technology Gap Assessment*** – *To impact PCOS/COR/ExEP 2016 technology cycle*	**June 30, 2016**
O2	***Optional: Update Technology Gap Assessments***	**June 2017**
M4a	**Interim Report** **March 2018** – Provide science case and mission concept (use CML 3 as a guide) – Deliver initial technology roadmaps; estimate technology development cost/schedule – CML 4 tailored approach (optional)	
O3	**Update Technology Gap Assessments**	**June 2018**
M4b	**Update Interim report with LRT comments incorporated (Public Release)**	**August 15, 2018**
M6a	**Required Input Data released by STDTs to HQ** – Support independent cost estimation/validation process – HQ submits to Large mission studies Cost Assessment Team (slide 35)	**April 26, 2019**
M6b	**LCIT reconciliation with STDTs**	**July 2019**
M7	**STDTs Final Reports delivered to HQ** – As described in study success criteria chart 15	**August 23, 2019**
M8	**HQ Submits final report to Decadal**	**September 2019**

Lynx Study Look Ahead

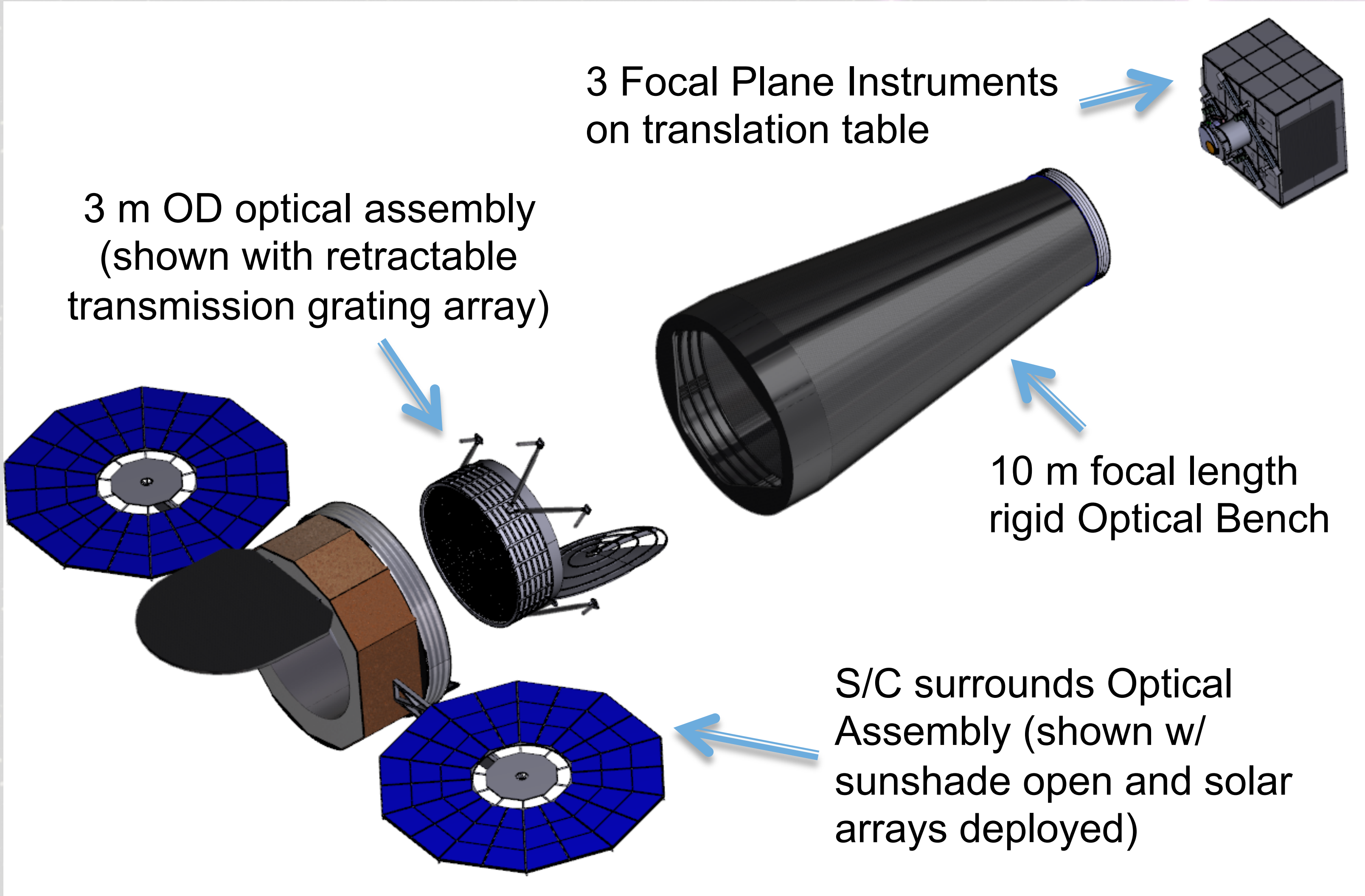


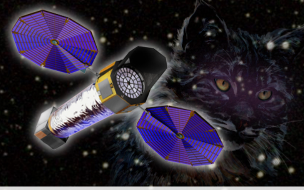
Lynx Study Look Ahead



Decadal decision anticipated ~December 2020

Proven Observatory Architecture

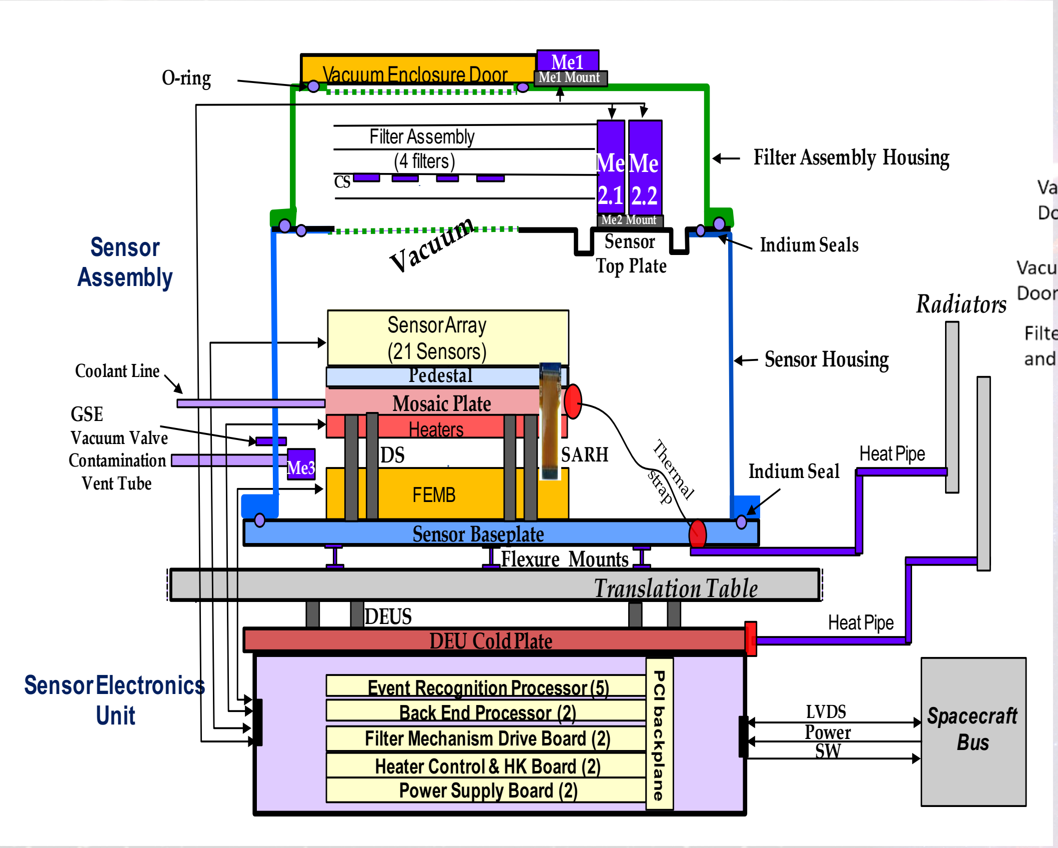


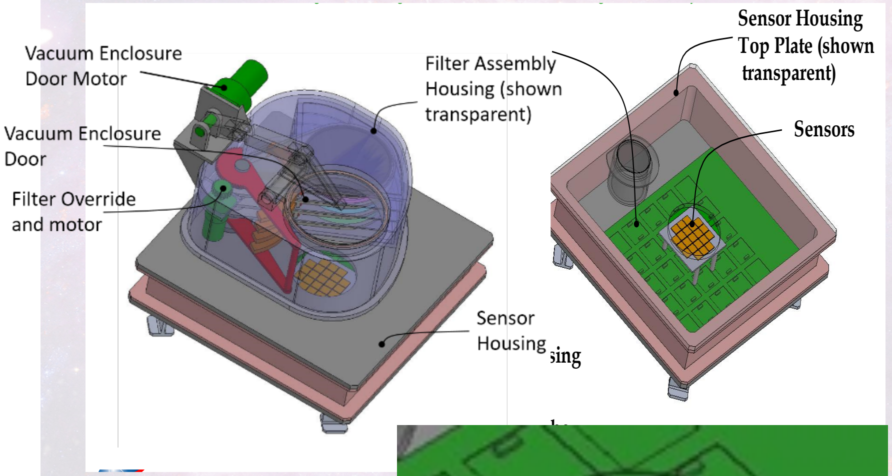


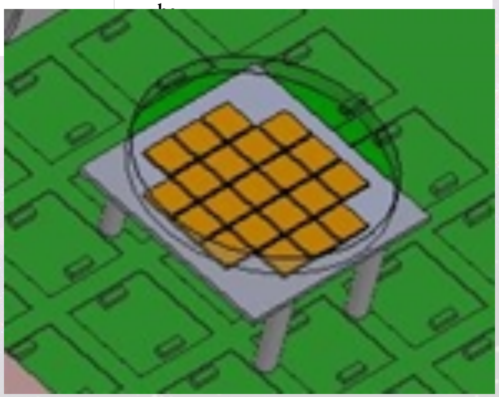
High-Definition X-ray Imager

Ralph Kraft, SAO
Abe Falcone, Penn State University
Mark Bautz, MIT

- Initial instrument design developed by MSFC Advanced Concepts Office (ACO)
- Fully samples Lynx 22’x22’ sub-arcsecond FOV
- >100 frames/s in full frame mode (10^4 in 20px20p window mode); >8000 c/s full field event rate

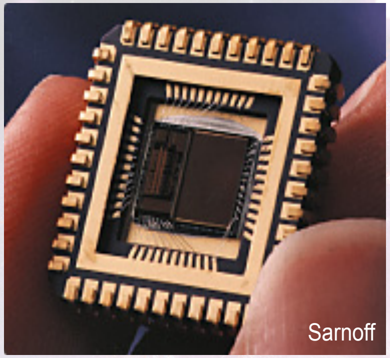




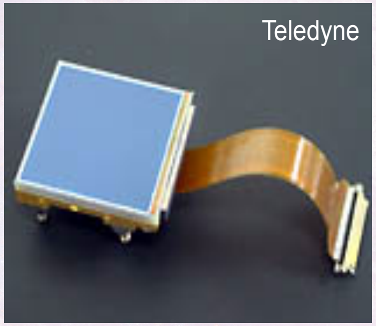


HDXI: Multiple Sensor Approaches

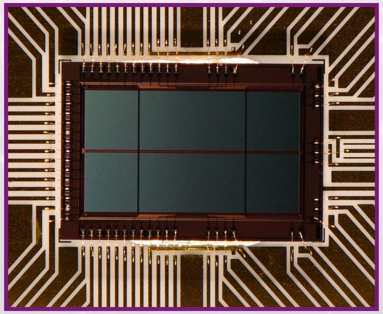
- Monolithic CMOS Active Pixel Sensor
  - Single Si wafer used for both photon detection and read out electronics
  - SRI/SAO (and MPE)



- Hybrid CMOS Active Pixel Sensor
  - Multiple bonded layers, with detection layer optimized for photon detection and readout circuitry layer optimized independently
  - Teledyne/PSU



- Digital CCD with CMOS readout
  - CCD Si sensor with multiple parallel readout ports and digitization on-chip
  - LL/MIT



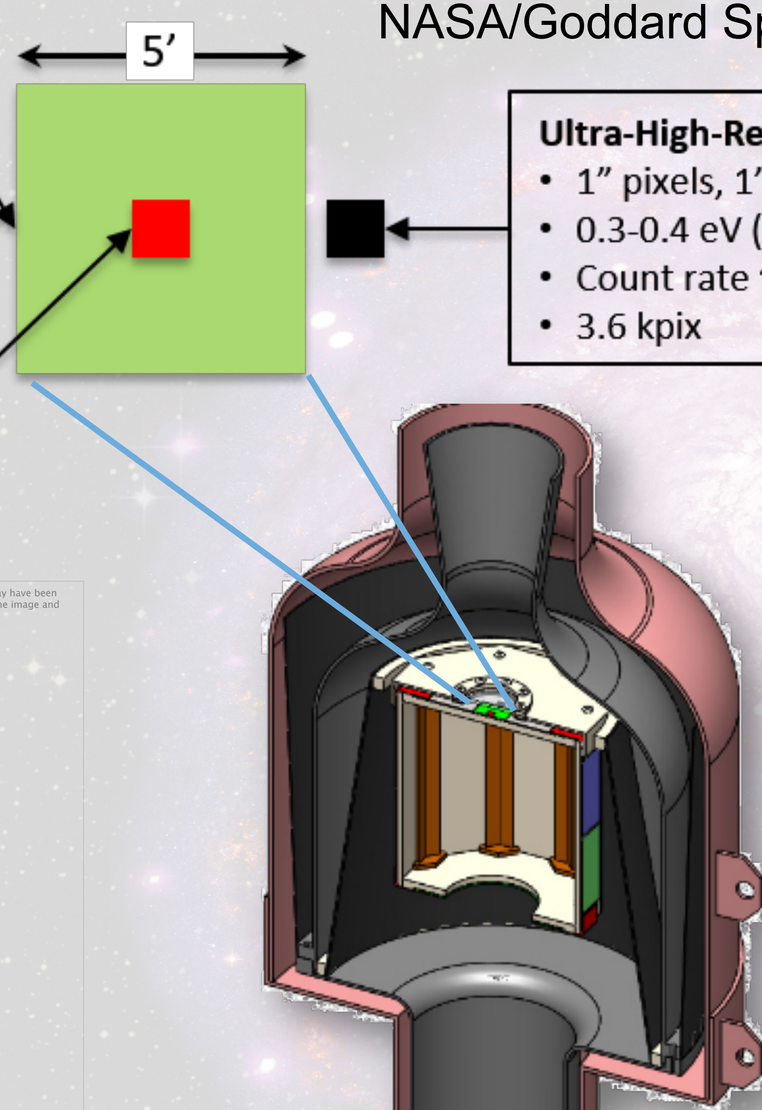
MIT Lincoln

Lynx X-ray Microcalorimeter

Simon Bandler
NASA/Goddard Space Flight Center

Main Array
- 1” pixels, 5’ FOV, 50 μm pixels
- ~3 eV, 10 cps/hydra (5”)
- Up to 7 keV
- 86.4 kpix

Enhanced Main Array
- 0.5” pixels, 1’ FOV, 25 μm pixels
- 1.5 eV, 20 cps/hydra (2.5”)
- Up to 7 keV
- 12.8 kpix



Ultra-High-Res Array
- 1” pixels, 1’ FOV, 50 μm pixels
- 0.3-0.4 eV (up to ~0.75 keV)
- Count rate ~80 cps/1” (single pixel)
- 3.6 kpix

109.47

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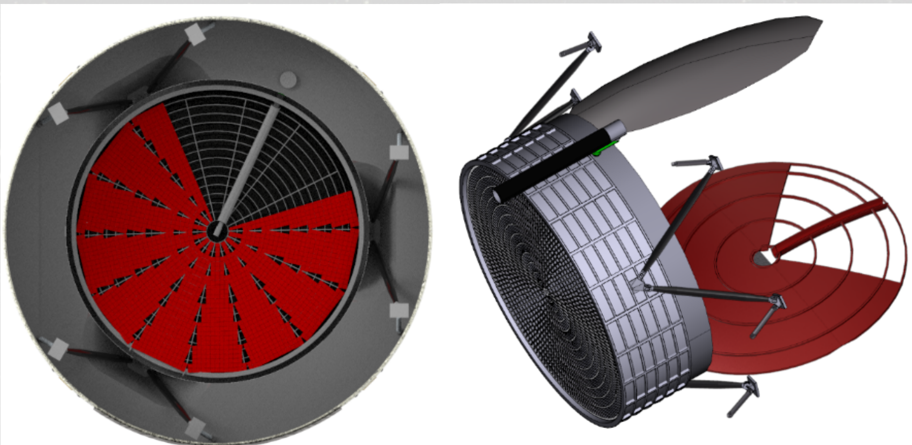
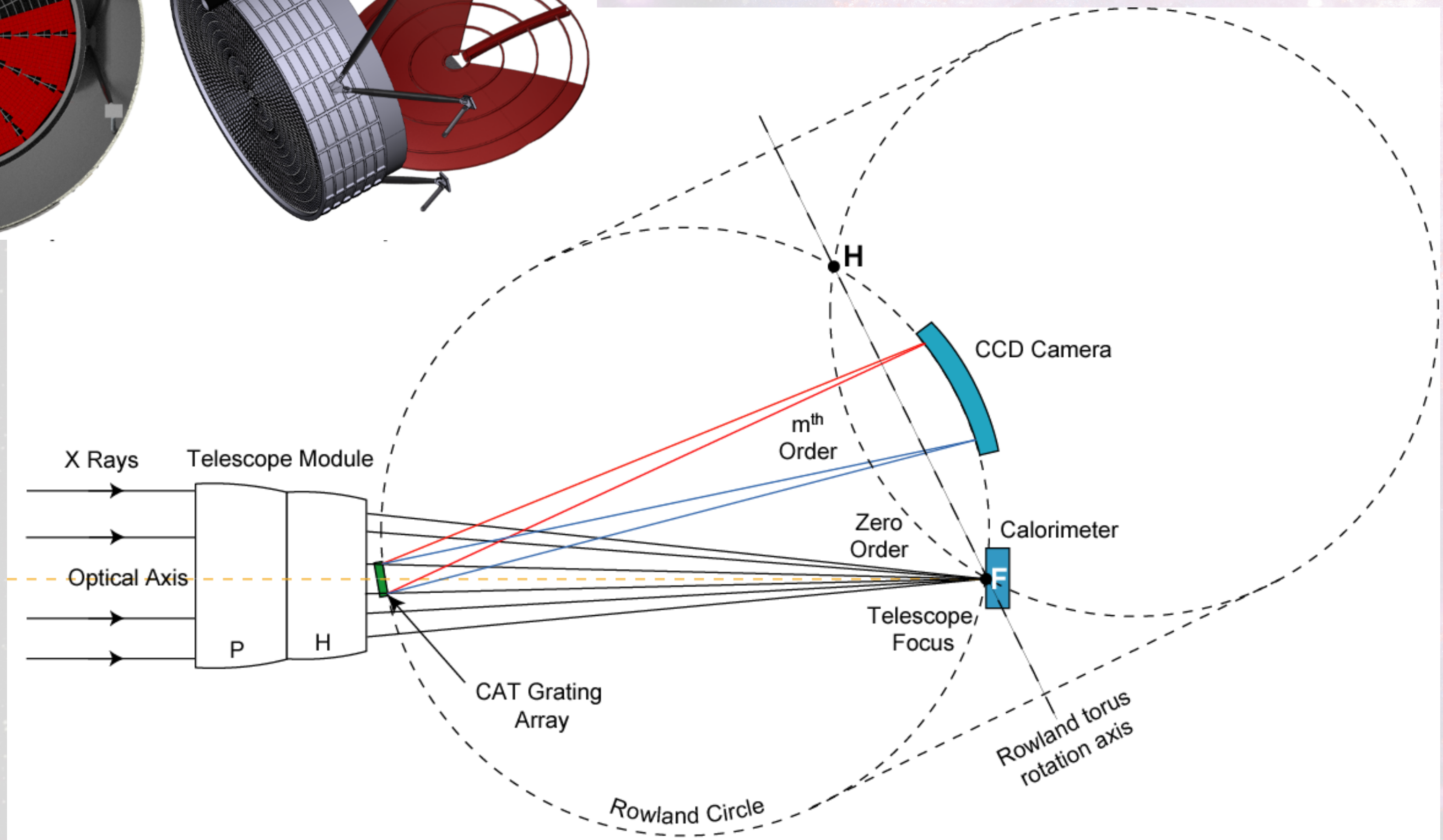
R>5000 X-ray Grating Spectrometer

Ralf Heilmann
Space Nanotechnology Lab
MIT Kavli Institute for
Astrophysics and Space Research





X-ray Mirror Assembly

Will Zhang
NASA/Goddard Space Flight Center

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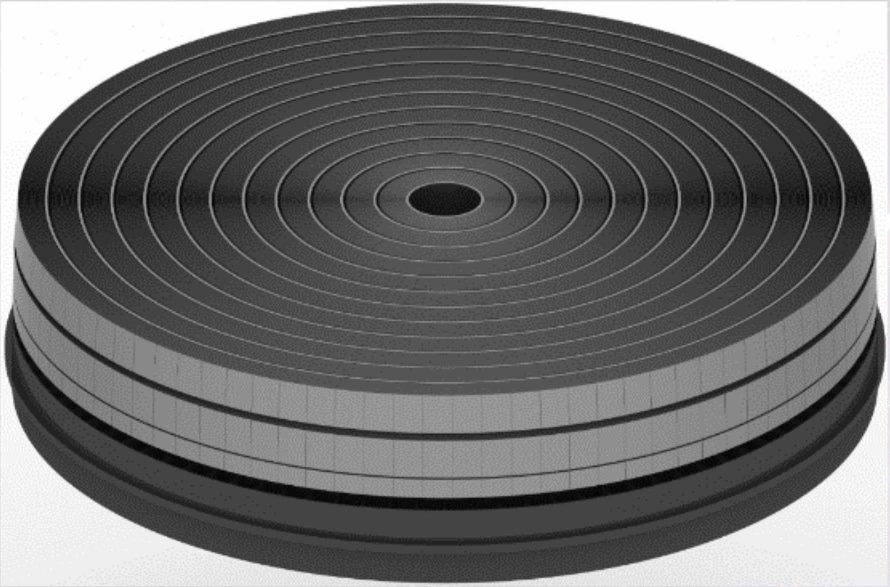


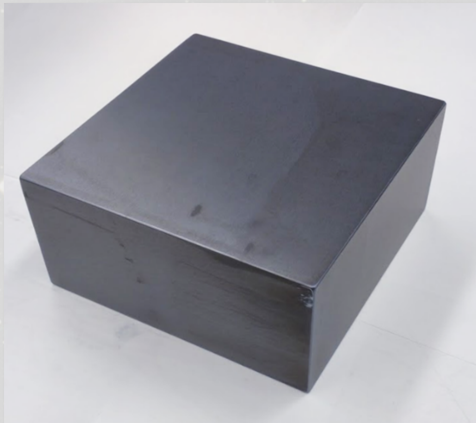
Silicon Meta-shell Optics recommended for DRM by LMAT

Focal Length:	10 m
Outer Diameter:	3 m

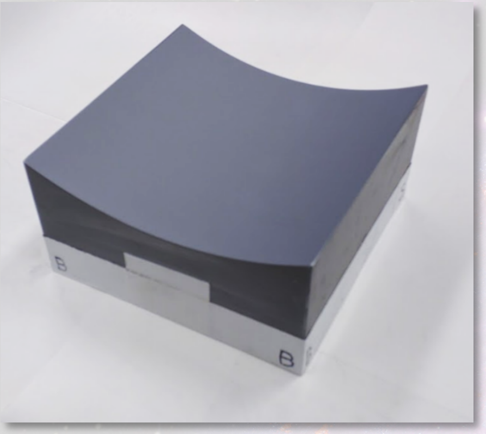
Effective Area	
1 keV	>2 m^2
6 keV	0.2 m^2

On-Axis HPD:	0.5”
FOV w/ 1” HPD:	10’

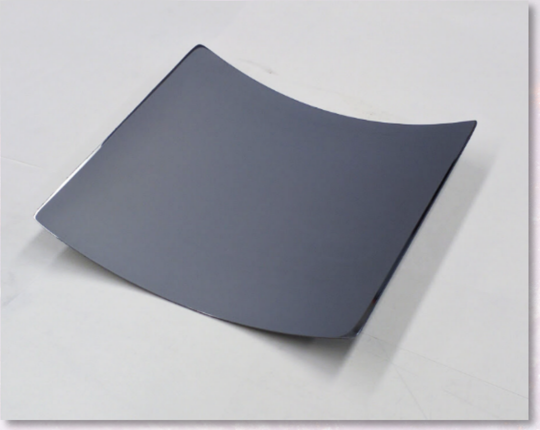
Direct-fabrication Mirror Segments



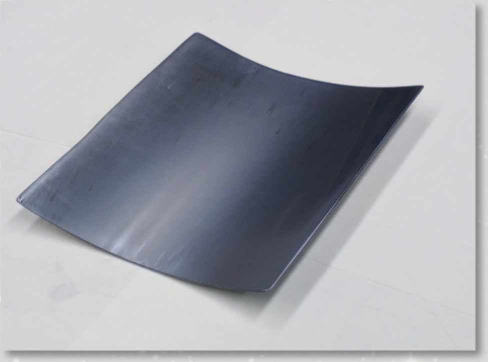
1. Mono-crystalline silicon block



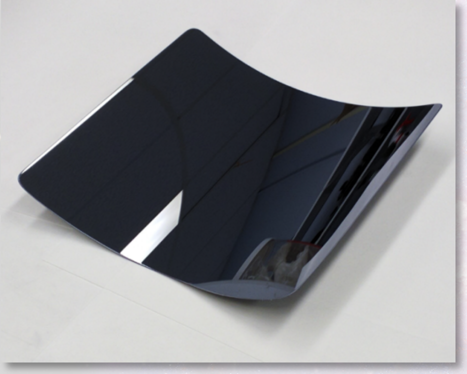
2. Conical form generated



3. Light-weighted substrate



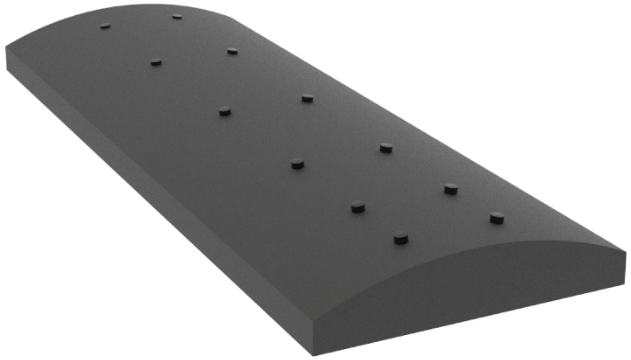
4. Etched substrate



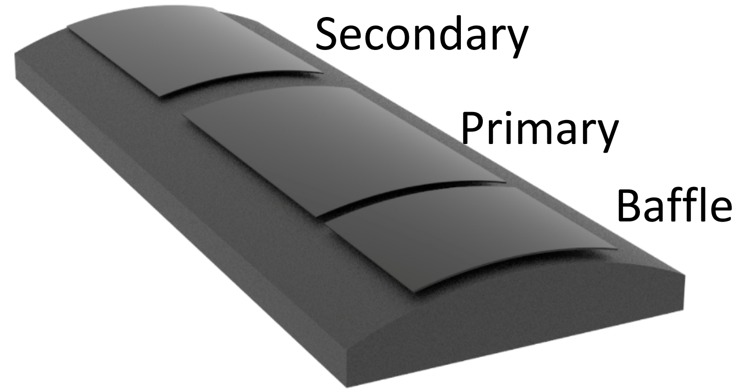
5. Polished mirror substrate

6. Trimmed mirror substrate

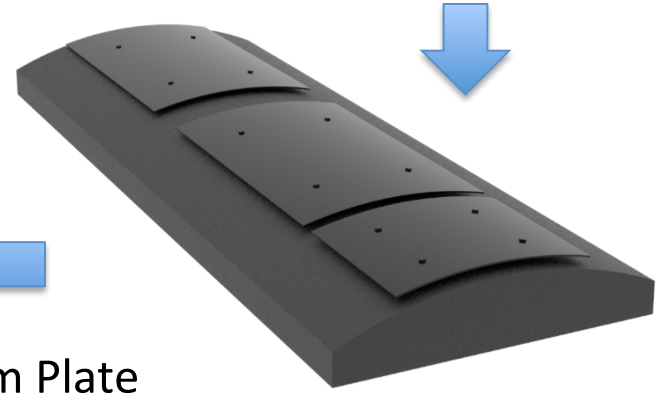
The Process of Building a Mirror Module



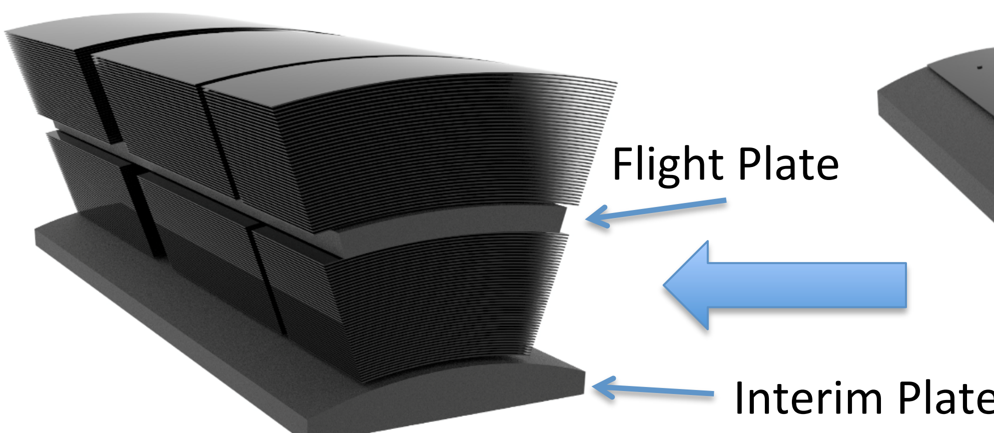
1. Silicon plate with small silicon spacers that are precisely ground to prescribed radial heights.



2. Mirror segments are placed on spacers, settled by vibrations. The baffle is shown for completeness and has no precision to speak of.

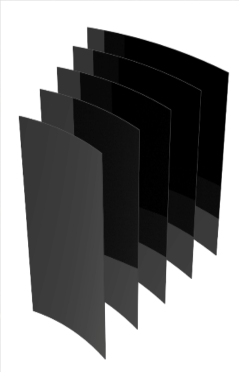
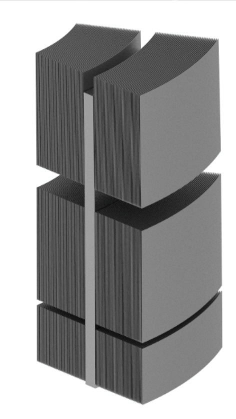
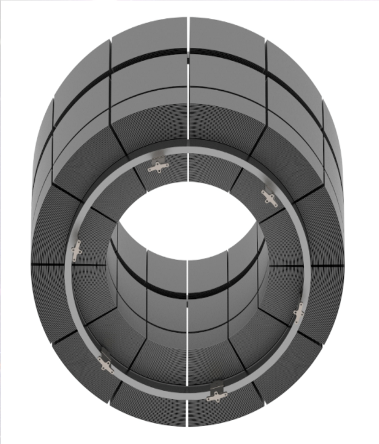
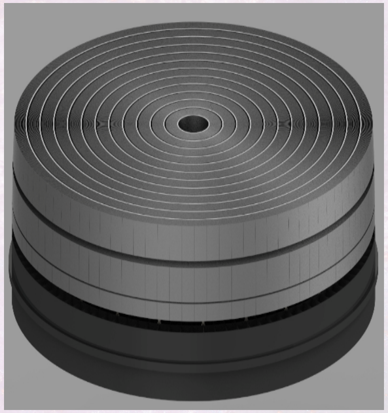


3. Once epoxy cures, another set of spacers are attached to repeat the process for the next layer of mirror segments.



4. The previous steps repeat until a full mirror module is completed. The interim silicon plate is removed at the end of the buildup process.

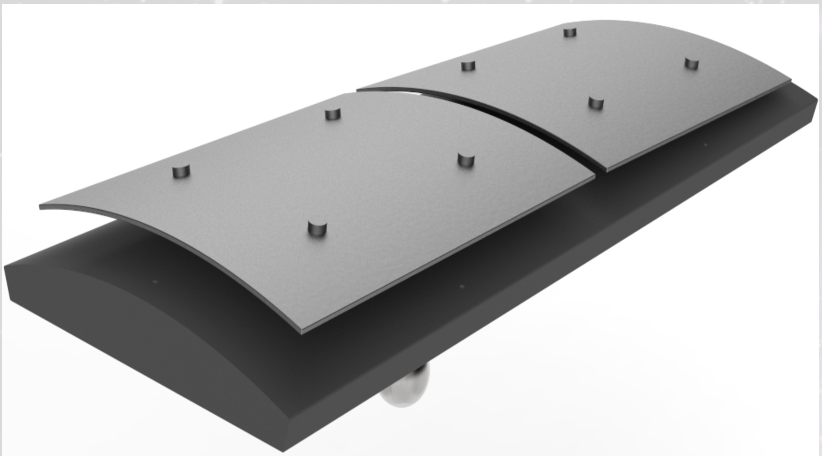
Steps in Lynx Mirror Assembly Build

37,492 Segments	611 Modules	12 Meta-shells	1 Assembly
			
~0.01 kg ea.	~1.5 kg ea.	~80 kg ea.	~1,000 kg

AI&T see **109.45**

Process Validated by X-ray Testing

Full Illumination X-ray Measurement at GSFC and MPE Panter



Effective Area at 4.5 keV (cm^2)

0.266 predicted

0.260 measured

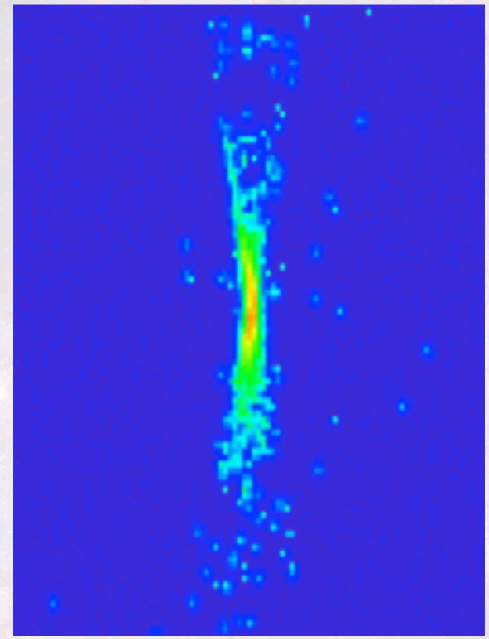


Image at 4.5 keV: 2.2” HPD (logarithmic color scale) approaches TRL 4